Richard W. Hamming

Learning to Learn

The Art of Doing Science and Engineering

Session 2: Foundations of Digital (Discrete) Revolution

Foundations of the Digital (Discrete) Revolution

1. Why has this revolution happened?

- Continuous signaling requires amplification for natural losses along the way. Errors made before or during amplification are amplified during the next stage.
- In discrete signaling, we use the incoming pulse to gate the input; we actually use repeaters for output. Noise introduced at on spot, if not too much to make the pulse detection wrong at the next repeater, is automatically removed.

Foundations of the Digital (Discrete) Revolution

2. Why has this revolution happened?

- Invention and development of transistors and integrated circuits (ICs).
- The high density of components in an IC means low cost and higher speeds of computing.
- Decrease in voltage and current levels of ICs has contributed to solving heat dissipation.

Foundations of the Digital (Discrete) Revolution

3. Why has this revolution happened?

- Society has moved from a material goods society to an information service society.
  - *American Revolution over 90% of the people were farmers*
  - *Before WWII most workers were in factories*
  - *1993, more people worked in government positions than in manufacturing and this number excludes those in the military.*

Foundations of the Digital (Discrete) Revolution

4. Why has this revolution happened?

- What will happen in 2020?
  - *25% of the civilian work force will handle things*
  - *75% of the civilian work force will handle information in some form or another.*
- Computers have made it possible for robots to do many jobs in current manufacturing facilities
- The addition of neural-net computers, fuzzy set logic and variations will control production.

Robots Used in Manufacturing 1

What are they used for?

- Produce a better product under tighter control limits.
- Produce usually a cheaper product
- Produce a different product.
  - *As we moved from hand fabrication to machine fabrication, we passed from screws and bolts to rivets and welding. This drove design changes.*
  - *It has rarely proved practical to produce exactly the same product by machines that we originally produced by hand.*

Robots Used in Manufacturing 1

Emergence of Imaginative Redesign

- Mechanization requires that you produce an equivalent product, not the same product.
- Now essential that field maintenance be considered
  - *The more complex the design, the more field maintenance must be central to the final design*
  - *Only when field maintenance is part of the original design can maintenance and upkeep be safely controlled; it is not wise to graft it on later.*

Effects of Computers on Science

Large-Scale Computing

- Computers allow the simulation of many different kinds of experiments.
  - *Mid 50’s: one out of ten experiments was done on a computer.*
  - *Mid 90’s: nine out of ten experiments are done on a computer.*
  - *Much cheaper and more flexible to do simulations than real experiments.*

Effects of Computers on Science

Computer Simulation

- One of the evils of the Middle Ages scholasticism: people deciding what would happen by reading, rather than by looking at Nature.
- The modern scientific revolution was started by Galileo’s great point: look at Nature, not in books!
- We must not forget, in all our enthusiasm for computer simulation, that occasionally we must look at Nature as She is.

Effects of Computers on Engineering

Computer Modeling

- We can build far more complex things, and we can explore many more alternate designs
- Use computers to work out problems in unstable designs
- Computers allow us to measure values accurately, even when right on the edge of stability/instability
- Engineering is coming closer to Science
- Computers are essential component of good design

Effects of Computers on Society

Computer Use in Business

- Computer have given top management the power to micromanage their organizations, and they have shown no restraint in doing so.
  - *Lower management does not get the chance to make responsible decisions and learn from their mistakes.*
  - *As senior management retire, lower management finds itself as top management with little to no experience.*

Effects of Computers on Society

Computer Use in Business

- Central planning has repeatedly been shown to give poor results.
- People on top do not often have the local view of all the details, many of which are important, and the people at the bottom do not have the global perspective. So either extreme gets poor results.
- Ideas that result from field experience rarely get implemented in centralized systems because of the “**not invented here”** (NIH) syndrome.

Effects of Computers on Society

Computer Use in Business

- Loose connections between small companies are on the rise.
- Much of this loose association between small organizations is a defense against micromanagement.
- Some companies will be able to give up micromanagement; most will be replaced in the long run by smaller organizations without the overhead costs and errors of top management.

Effects of Computers In Entertainment

How far will machines go

- We watch TV more each day than we spend eating.
- Use of computers on chips to personal areas such as marriage, sex, sports, games, “travel in the comfort of home via virtual realities” and other human activities.
- The Internet
- Computers went from number crunching to information retrieval.

Effects of Computers In the Military

An Information War

- In the Gulf War we saw examples that failure to use information about one’s own situation killed many of our own people.
- “The battle field is no place for the human being.”
- Many of you will insist on old doctrines you were taught as if they would be automatically true in the long future.

Effects of Computers In the Military

An Information War

- You must rethink everything you ever learned on the subject, question every successful doctrine from the past, and finally decide for yourself its future applicability.
- Buddha said, “Believe nothing, no matter where you read it, or who said it, no matter if I have said it, unless it agrees with your own reason and your own common sense.”
- You must assume responsibility for what you believe.

Rate of Evolution

"S" shaped curve

$$dy/dt = ky$$

$$y(t) = Ae^{kt}$$

Rate of Evolution

All things must have limits

$$dy/dt = ky(L - y)$$

$$dz/dx = z(1 - z)$$

Rate of Evolution

All things must have limits

$$\ln z - l(1 - z) = x + c$$

$$z/(1 - z) = Ae^{x}$$

$$z = 1/[1 + (1/A)e^{-x}]$$

Rate of Evolution

Flexible Growth Model

$$dz/dx = z^a (1 - z)^b$$

$$(a, b > 0)$$

Rate of Evolution

Flexible Growth Model- Numerical Integration

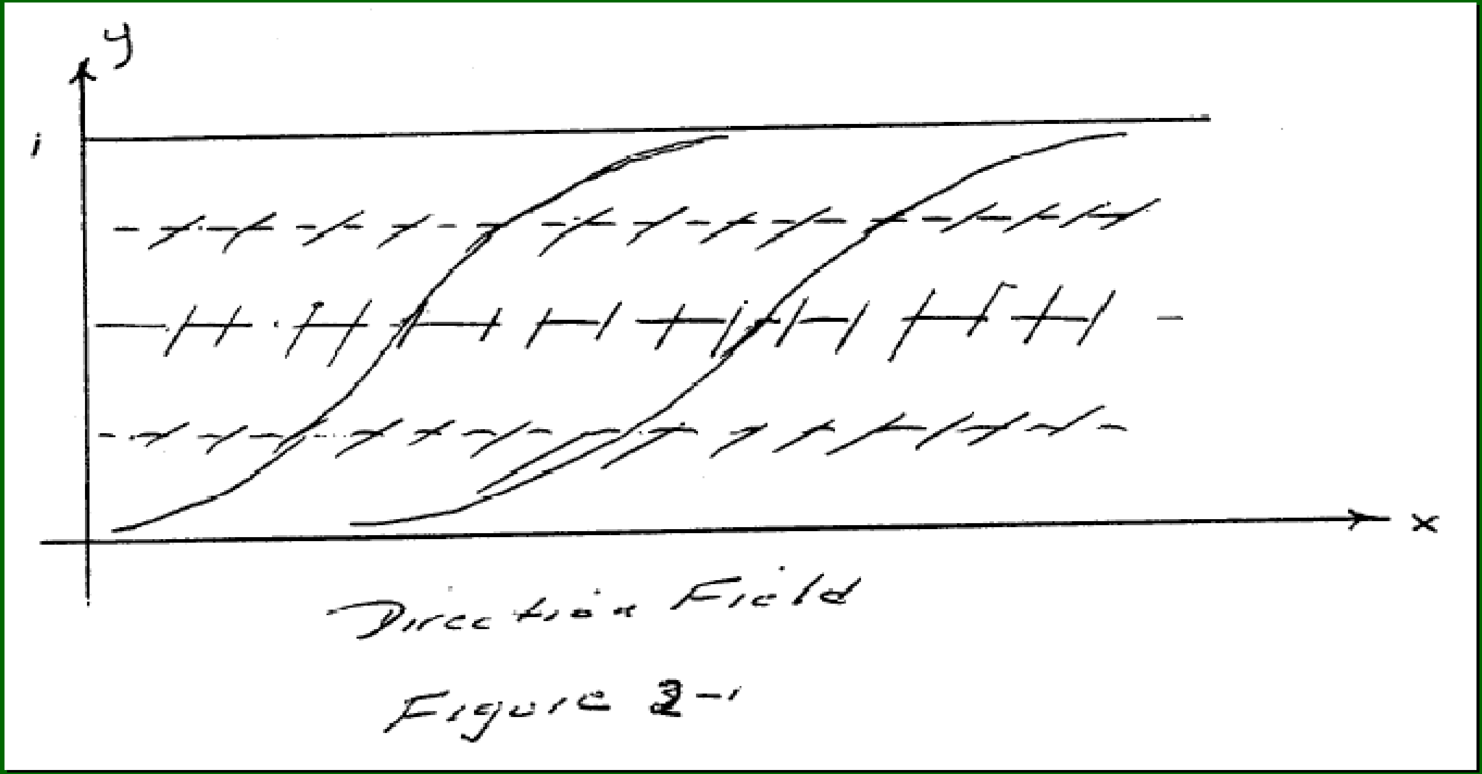
$$a(1-z)-bz=0$$

$$z=a/(a+b)$$

$$a^a b^b/(a+b)^{a+b}$$

Rate of Evolution

Direction Field Sketch



Rate of Evolution

Direction Field Sketch

$$\text{maximum slope} = 1/2^{2a}$$

$$z = \sin 2(x/2 + c)$$

$$(-c \le x/2 \le \pi - c)$$

von Neumann Single Processor

Computer

- The world is made out of molecules
- Using the evidence that the two relativity theories, special and general, gives a maximum speed of useful signaling, then there are definite limits to what can be done with a single processor.
- New innovation will set the growth field onto a new “S” curve that takes off from around the saturation level of the old one.

von Neumann Single Processor

New “S” Curve

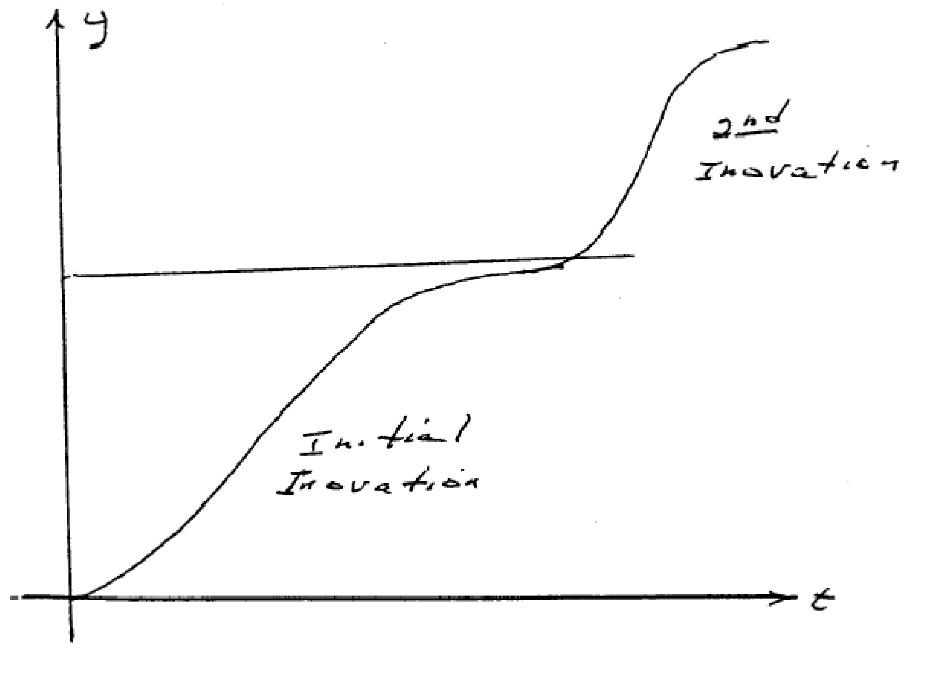


Figure 2-2

Use of General Purpose Chips

- Other users of the chip will help find the errors, or other weaknesses, if there are any.
- Other users will help write the manuals needed to use it,
- Other users, including the manufacturer, will suggest upgrades of the chip, hence you can expect improved chips.
- Inventory will not be a serious problem.
- Upgradeable by mere program changes.

Hence beware of special purpose chips!